

$B_s^0 \rightarrow D_s^- a_1^+$ decay channel in the B_s^0 -mixing studies

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Abstract

The usefulness of the $B_s^0 \rightarrow D_s^- a_1^+, D_s^- \rightarrow \phi \pi^- \rightarrow K^+ K^- \pi^-, a_1^+ \rightarrow \rho^0 \pi^+ \rightarrow \pi^+ \pi^- \pi^+$ decay chain is investigated for the B_s -reconstruction in the future ATLAS B_s -mixing experiment. It is shown that this decay channel is almost as suitable for this purpose as previously studied $B_s^0 \rightarrow D_s^- \pi^+$.

1 Introduction

In the Standard Model B^0 and \bar{B}^0 are not mass eigenstates. Instead we have (the small CP-violating effects are neglected)

$$B^0 = \frac{B_1 + B_2}{\sqrt{2}} \quad \bar{B}^0 = \frac{B_1 - B_2}{\sqrt{2}} . \quad (1)$$

So the time evolution of the B_i states looks like

$$B_i(t) = B_i(0) \exp \left\{ -\frac{i}{\hbar} (m_i - i \frac{\Gamma_i}{2}) t \right\} , \quad (2)$$

where m_i is the mass eigenvalue and Γ_i - the corresponding width.

It follows from (1) and (2) that the probability for B^0 meson not to change its flavour after a time t from the creation is

$$P^{B^0 B^0}(t) = |\langle B^0(t) | B^0(0) \rangle|^2 = \frac{1}{2} e^{-\frac{\Gamma t}{\hbar}} \left(\cosh \frac{\Delta \Gamma t}{2\hbar} + \cos \frac{\Delta m t}{\hbar} \right) , \quad (3)$$

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and the probability to convert into the \bar{B}^0 meson –

$$P^{B^0\bar{B}^0}(t) = |\langle \bar{B}^0(t) | B^0(0) \rangle|^2 = \frac{1}{2} e^{-\frac{\Gamma t}{\hbar}} \left(\cosh \frac{\Delta\Gamma t}{2\hbar} - \cos \frac{\Delta m t}{\hbar} \right), \quad (4)$$

where $\Gamma = \frac{1}{2}(\Gamma_1 + \Gamma_2)$ is the average width and $\Delta\Gamma = \Gamma_1 - \Gamma_2$. So $\Delta m = m_1 - m_2$ mass difference between the B mass eigenstates defines the oscillation frequency. Standard Model predicts [1] that $\frac{\Delta m_s}{\Delta m_d} \sim \left| \frac{V_{ts}}{V_{td}} \right|^2 \gg 1$, V_{ij} being the Cabibbo-Kobayashi-Maskawa matrix element. Therefore the mixing in the B_s^0 meson system proceeds much more faster than in the B_d^0 system.

The total probability χ that a B^0 will oscillate into \bar{B}^0 is

$$\chi = \int_0^\infty P^{B^0\bar{B}^0}(t) \frac{dt}{\tau} (1 - y^2) = \frac{1}{2} \left(\frac{x^2}{1 + x^2} + \frac{y^2}{1 - y^2} \right) (1 - y^2), \quad x = \frac{\Delta m}{\Gamma}, \quad y = \frac{\Delta\Gamma}{2\Gamma}. \quad (5)$$

In the first B_d -mixing experiments [2] just this time integrated mixing probability was measured. The result [3] $x_d = 0.69 \pm 0.07$ shows that in the B_s system $x_s \gg 1$ is expected. In fact the allowed range of x_s is estimated to be between ~ 12 and ~ 30 in the Standard Model [4]. Such a big value of x_s makes impossible time integrated measurements in the B_s system, because χ in (5) saturates at ~ 0.5 for large values of x .

Although it was thought that unlike the kaon system for the B mesons the decay width difference can be neglected [5], nowadays people is more inclined to believe the theoretical prediction [6] that the $b \rightarrow c\bar{c}s$ transition, with final states common to both B_s and \bar{B}_s , can generate about 20% difference in lifetimes of the short lived and long lived B_s -mesons [7].

But we can see from the (3 ÷ 5) formulas that the effect of nonzero y is always $\sim y^2$ and so of the order of several percents, because $y \approx 0.1$ is expected. In the following we will neglect this effect and will take $y = 0$, though in some formulas y is kept for reference reason.

The development of high precision vertex detectors made it possible to measure [8] in the B_d system the time dependent asymmetry

$$\frac{P^{B^0 B^0} - P^{B^0 \bar{B}^0}}{P^{B^0 B^0} + P^{B^0 \bar{B}^0}} = \cos \frac{\Delta m t}{\hbar}. \quad (6)$$

The same techniques can also be applied to the $B_s - \bar{B}_s$ system.

Recently the ATLAS detector sensitivity to the x_s parameter was studied [9] using $B_s^0 \rightarrow D_s^- \pi^+ \rightarrow \phi \pi^- \pi^+ \rightarrow K^+ K^- \pi^- \pi^+$ decay chain for B_s meson reconstruction. It was shown that x_s up to 40 should be within a reach [10]. The signal statistics could be increased by using other decay channels, like $B_s^0 \rightarrow D_s^- a_1^+$, $B_s^0 \rightarrow J/\Psi K^{*0}$.

The purpose of this note is to study the usefulness of the decay chain $B_s^0 \rightarrow D_s^- a_1^+ \rightarrow \phi \pi^- \rho \pi^+ \rightarrow K^+ K^- \pi^- \pi^+ \pi^- \pi^+$ for B_s meson reconstruction in the ATLAS B_s -mixing experiments.

2 Event simulation

About 20 000 following b-decays were generated using the PYTHIA Monte Carlo program [11]

$$\begin{aligned}
(p_T^\mu > 6 \text{ GeV}/c, |\eta^\mu| < 2.2) \mu_{tag} \leftarrow b\bar{b} \rightarrow B_s^0 \rightarrow D_s^- a_1^+ \\
&\quad \hookrightarrow \rho^0 \pi^+ \\
&\quad \hookrightarrow \pi^+ \pi^- \\
&\quad \hookrightarrow \phi \pi^- \\
&\quad \hookrightarrow K^+ K^-
\end{aligned}$$

The impact parameter was smeared using the following parameterized description of the impact parameter resolution

$$\sigma_{IP} = 14 \oplus 72/(p_T \sqrt{|\sin \theta|}) \quad \sigma_Z = 20 \oplus 83/(p_T \sqrt{|\sin \theta|^3}) \quad , \quad (7)$$

where resolutions are in μm and θ is the angle with respect to the beam line. It was shown in [9] that this parameterized resolution reasonably reproduces the results obtained by using the full simulation and reconstruction programs.

For the transverse momentum resolution an usual expression [10]

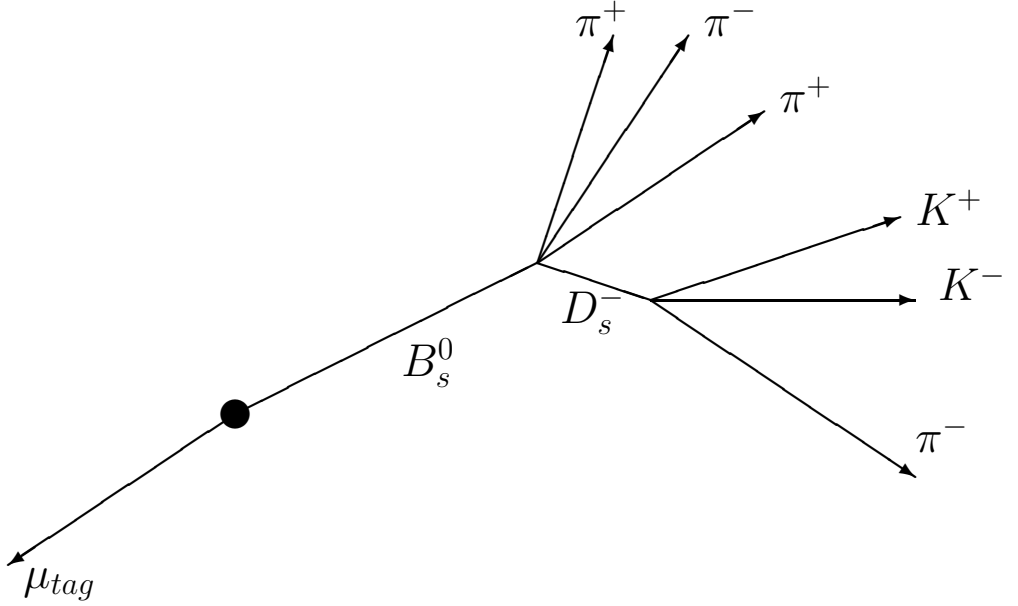
$$\frac{\sigma(p_T)}{p_T} = 5 \cdot 10^{-4} p_T \oplus 1.2\% \quad (8)$$

was assumed.

Track reconstruction efficiencies for various particles were taken from [10]. Because now we have 6 particles in the final state instead of 4 for the $B_s^0 \rightarrow D_s^- \pi^+$ decay channel, we expect some loss in statistics due to track reconstruction inefficiencies, but the effect is not significant because the investigation in [10] indicates a high reconstruction efficiency of 0.95.

3 Event reconstruction

The topology of a considered B_s^0 decay chain is shown schematically in a figure:



The B_s decay vertex reconstruction was done in the following three steps.

First of all the D_s^- was reconstructed by finding three charged particles presumably originated from the D_s^- decay and fitting their tracks. For this goal all combinations of the properly charged particles were examined in the generated events, assuming that two of them are kaons and one is pion. The resulting invariant mass distribution is shown in Fig.1a for signal events. The expected D_s^- peak is clearly seen along with moderate enough combinatorial background. Cuts on $\Delta\phi_{KK}$, $\Delta\Theta_{KK}$ and $|M_{KK} - M_\phi|$ were selected in order to optimize signal to background ratio. To select one more cut on $|M_{KK\pi} - M_{D_s^-}|$, the information about the invariant mass resolution is desirable. Fig. 2a shows the reconstructed D_s^- meson from its true decay products. The finite invariant mass resolution is due to applied track smearing and equals approximately to $10\text{MeV}/c^2$.

After D_s^- meson reconstruction, a_1^+ meson was searched in three particle combinations from the remaining charged particles, each particle in the combination being assumed to be a pion. Fig. 1b shows a resulting invariant mass distribution for signal events. Because of huge width of a_1^+ , signal to background separation is not so obvious in this case. If a_1^+ is reconstructed from its true decay products as in Fig. 2b, its width is correctly reproduced. To draw out a_1^+ from the background, further cuts were applied on $\Delta\phi_{\pi\pi}$, $\Delta\Theta_{\pi\pi}$, $|M_{\pi\pi} - M_\rho|$ and $|M_{\pi\pi\pi} - M_{a_1}|$.

At last B_s^0 decay vertex was fitted, using reconstructed D_s^- and a_1^+ .

Almost the same resolution in the B_s -decay proper time was reached $\sigma_\tau \approx 0.064\text{ps}$, as in [9]. The corresponding resolution in the B-meson decay length in the transverse plane is $\approx 87\mu\text{m}$. The relevant distributions are shown in Fig.3.

4 Signal and background

Branching ratios and signal statistics for the $B_s^0 \rightarrow D_s^- a_1^+$ channel are summarized in Table 1. Note that we use an updated value for $\text{Br}(D_s^- \rightarrow \phi \pi^-)$ from [12]. B_s^0 branching ratios are still unknown experimentally. Neglecting SU(3) unitary symmetry breaking effects, we have taken $\text{Br}(B_s^0 \rightarrow D_s^- a_1^+) \approx \text{Br}(B^0 \rightarrow D^- a_1^+)$.

Table 1.
Branching ratios and signal statistics for $B_s^0 \rightarrow D_s^- a_1^+(1260)$.

| Parameter | Value | Comment |
|--|-----------------------|---|
| $L [cm^{-2}s^{-1}]$ | 10^{33} | |
| $t [s]$ | 10^7 | |
| $\sigma(b\bar{b})/\sigma(tot)$ | $\simeq 1/100$ | |
| $\sigma(b\bar{b}) [\mu b]$ | $\simeq 500$ | |
| $\sigma(b\bar{b} \rightarrow \mu X) [\mu b]$ | $\simeq 2.24$ | $p_T^\mu > 6 \text{ GeV}/c$ $ \eta^\mu < 2.2$ |
| $N(b\bar{b} \rightarrow \mu X)$ | 2.24×10^{10} | |
| $Br(b \rightarrow B_s^0)$ | 0.1 | |
| $Br(B_s^0 \rightarrow D_s^- a_1^+)$ | 0.006 | |
| $Br(D_s^- \rightarrow \phi \pi^-)$ | 0.035 | |
| $Br(\phi \rightarrow K^+ K^-)$ | 0.491 | |
| $Br(a_1^+ \rightarrow \rho^0 \pi^+)$ | ~ 0.5 | |
| $Br(\rho^0 \rightarrow \pi^- \pi^+)$ | ~ 1 | |
| $N(K^+ K^- \pi^- \pi^+ \pi^- \pi^+)$ | 116000 | |

Acceptance and analysis cuts are summarized in Table 2. We take a track reconstruction efficiency of 95% and a lepton identification efficiency of 80%, as in [10].

Table 2.

Analysis cuts and acceptance for $B_s^0 \rightarrow D_s^- a_1^+(1260)$ (for $10^4 pb^{-1}$ integrated luminosity).

| Parameter | Value | Comment |
|--|------------|---------|
| $N(K^+ K^- \pi^- \pi^+ \pi^- \pi^+)$ | 116000 | |
| Cuts : $p_T > 1 \text{ GeV}/c$ $ \eta < 2.5$ | | |
| $N(K^+ K^- \pi^- \pi^+ \pi^- \pi^+)$ | 7680 | 6.6% |
| $\Delta\varphi_{KK} < 10^\circ$ $\Delta\theta_{KK} < 10^\circ$ $ M_{KK} - M_\phi < 20 \text{ MeV}/c^2$ $ M_{KK\pi} - M_{D_s^-} < 15 \text{ MeV}/c^2$ $\Delta\varphi_{\pi\pi} < 35^\circ$ $\Delta\theta_{\pi\pi} < 15^\circ$ $ M_{\pi\pi} - M_{\rho^0} < 192 \text{ MeV}/c^2 (\pm 3\sigma)$ $ M_{\pi\pi\pi} - M_{a_1^+} < 300 \text{ MeV}/c^2$ | | |
| $N(K^+ K^- \pi^- \pi^+ \pi^- \pi^+)$ | 5765 | 5.0% |
| D_s^- vertex fit $\chi^2 < 12.0$ a_1^+ vertex fit $\chi^2 < 12.0$ B_s^0 vertex fit $\chi^2 < 0.35$ B_s^0 proper decay time $> 0.4 \text{ ps}$ B_s^0 impact parameter $< 55 \text{ } \mu\text{m}$ B_s^0 $p_T > 10.0 \text{ GeV}/c$ | | |
| $N(K^+ K^- \pi^- \pi^+ \pi^- \pi^+)$ after cuts | 3505 | 3.0% |
| Lepton identification | 0.8 | |
| Track efficiency | $(0.95)^6$ | |
| $N(K^+ K^- \pi^- \pi^+ \pi^- \pi^+)$ reconstructed | 2065 | 1.8% |

As we see, about 2065 reconstructed B_s^0 are expected after one year run at $\mathcal{L} = 10^{33} cm^{-2} s^{-1}$ luminosity. The corresponding number of events within one standard deviation ($\simeq 22 \text{ MeV}/c^2$) from the B_s^0 mass equals 1407. This last number should be compared to 2650 signal events, as reported in [10], when $B_s^0 \rightarrow D_s^- \pi^+$ decay channel is used.

Events which pass the first level muon trigger ($p_T > 6 \text{ GeV}/c$, $|\eta| < 2.2$) are predominantly $b\bar{b}$ events. Background can come from other B decays of the same or higher charged multiplicity, and from random combinations with some (or all) particles originating not from a B decay (combinatorial background).

The following channels were considered and no significant contributions were found to the background:

- $B_d^0 \rightarrow D^- a_1^+$. These events don't pass the analysis cuts, because the D^- mass is shifted from the D_s^- mass by about 100 MeV, and so does the B_d^0 mass compared to the B_s^0 mass.
- $\Lambda_b \rightarrow \Lambda_c^+ \pi^-$ followed by $\Lambda_c^+ \rightarrow p K^- \pi^+ \pi^+ \pi^-$. Taking $Br(\Lambda_b \rightarrow \Lambda_c^+ \pi^-) \approx 0.01$ from [13], we see that the expected number of $pK4\pi$ events, originated from this

source, is only five times less than the expected number of truly signal events. But the decay topology for this decay chain is drastically different (1+5, not 3+3) and therefore it is unexpected that significant amount of the B-decays will be simulated in this way.

Note that even for $B_s \rightarrow D_s^- \pi^+$ decay channel the similar background is negligible [9], although $Br(\Lambda_c^+ \rightarrow p K^- \pi^+)$ is about 44 times bigger than $Br(\Lambda_c^+ \rightarrow p K^- \pi^+ \pi^+ \pi^-)$.

- $B_d^0 \rightarrow D_s^- a_1^+$. About 10 000 such events were generated by PYTHIA and then analyzed. Using $Br(B_d^0 \rightarrow D_s^+ a_1^-) < 2.7 \cdot 10^{-3}$ from [12] and assuming that $B_d^0 \rightarrow D_s^- a_1^+$ decay goes through $B^0 \bar{B}^0$ oscillations: $B_d^0 \rightarrow \bar{B}_d^0 \rightarrow D_s^- a_1^+$, and therefore $Br(B_d^0 \rightarrow D_s^- a_1^+) = \chi_d Br(B_d^0 \rightarrow D_s^+ a_1^-) < 4.3 \cdot 10^{-4}$, we have got Fig.4. It is seen from this figure that because of $M_{B_s} - M_{B_d} \approx 100 MeV$ mass shift, the contribution of this channel to the background proves to be negligible.

Note that Fig.4 refers to the total number of the $B_d^0 \rightarrow D_s^- a_1^+$ events. In fact the distribution of these events with regard to the decay proper time is oscillatory, x_d (not x_s) defining the oscillation frequency. So in general this will result in oscillatory dilution factor. The conclusion that this dilution factor is irrelevant relies on the fact that no candidate event was found with invariant mass within one standard deviation from the B_s mass for $6 \cdot 10^4 pb^{-1}$ integrated luminosity.

A huge Monte-Carlo statistics is needed for combinatorial background studies. No candidate event with $M_{B_s^0} - 150 MeV/c^2 < M_{KK\pi\pi\pi\pi} < M_{B_s^0} + 150 MeV/c^2$ was found within $\sim 3 \cdot 10^5$ inclusive μX events. This indicates that signal/background ratio is expected to be not worse than 1:1.

5 Dilution factors

The observation of the $B - \bar{B}$ oscillations is complicated by some dilution factors. First of all the decay proper time is measured with some accuracy σ . From previous discussions we know that in our case $\sigma = 0.064 ps$ is expected. Due to this finite time resolution, the observed oscillations are convolutions of the expressions (3) and (4) given above with a Gaussian distribution. For example

$$P^{B^0 \bar{B}^0} \rightarrow \frac{1}{2} \int_{-\infty}^{\infty} e^{-\frac{\Gamma s}{\hbar}} \left(\cosh \frac{\Delta \Gamma t}{2\hbar} - \cos \frac{\Delta m s}{\hbar} \right) \exp \left[-\frac{(t-s)^2}{2\sigma^2} \right] \frac{ds}{\sqrt{2\pi}\sigma} \sim$$

$$\frac{1}{2} e^{-\frac{\Gamma t}{\hbar}} \left(\cosh \frac{\Delta \Gamma}{2\hbar} (t - \sigma \frac{\sigma}{\tau}) - D_{time} \cos \frac{\Delta m}{\hbar} (t - \sigma \frac{\sigma}{\tau}) \right) , \quad (9)$$

where $D_{time} = \exp \left[-\frac{1}{2} \left(\frac{\sigma}{\tau} \right)^2 (x^2 + y^2) \right]$, $\tau = \frac{\hbar}{\Gamma}$.

So the main effect of this smearing is the reduction of the oscillation amplitude by D_{time} . This is quite important in the B_s system where $x \gg 1$. There is also a time shift $t \rightarrow t - \sigma \frac{\sigma}{\tau}$ in (9). This time shift does not really effect the observability of the oscillations and we will neglect it.

In fact (9) is valid only for not too short decay times $t \gg \sigma$, because in (3) and (4) distributions $t > 0$ is assumed.

Another reduction in the oscillation amplitude is caused by the particle/ antiparticle mistagging at $t=0$. In our case particle/antiparticle nature of the B meson is tagged by the lepton charge in the semileptonic decay of the associated beauty hadron. Mistagging is mainly due to

- $B - \bar{B}$ oscillations: accompanying b-quark can be hadronized as a neutral B meson and oscillate into \bar{B} before semileptonic decay.
- $b \rightarrow c \rightarrow l^+$ cascade process, then the lepton is misidentified as having come directly from the B -meson and associated to the $\bar{b} \rightarrow l^+$ decay.
- leptons coming from other decaying particles (K, π, \dots).
- detector error in the lepton charge identification.

Let η be the mistagging probability. If we have tagged N B^0 mesons, among them only $(1 - \eta)N$ are indeed B^0 -s and ηN are \bar{B}^0 -s misidentified as B^0 -s. So at the proper time t we would observe $(P^{\bar{B}^0 \bar{B}^0}(t) = P^{B^0 B^0}(t)$ due to CPT invariance)

$$N \left[(1 - \eta) P^{B^0 \bar{B}^0}(t) + \eta P^{B^0 B^0}(t) \right] = \frac{N}{2} e^{-\frac{\Gamma t}{\hbar}} \left[\cosh \frac{\Delta \Gamma t}{2\hbar} - (1 - 2\eta) \cos \frac{\Delta m t}{\hbar} \right]$$

decays associated to the \bar{B}^0 meson and therefore

$$P^{B^0 \bar{B}^0}(t) \rightarrow \frac{1}{2} e^{-\frac{\Gamma t}{\hbar}} \left[\cosh \frac{\Delta \Gamma t}{2\hbar} - (1 - 2\eta) \cos \frac{\Delta m t}{\hbar} \right] .$$

So the dilution factor due to mistagging is $D_{tag} = 1 - 2\eta$. In our studies we have taken $D_{tag} = 0.56$, as in [14].

Finally the dilution can emerge from background. Suppose that apart from

$$\frac{N_{signal}}{2} e^{-\frac{\Gamma t}{\hbar}} \left(\cosh \frac{\Delta \Gamma t}{2\hbar} - \cos \frac{\Delta m t}{\hbar} \right)$$

events with $B \rightarrow \bar{B}$ oscillations we also have $N_{back}(t)$ additional background events. Half of them will simulate \bar{B} meson and half of them B meson (assuming asymmetry free background). So the observed number of would be $B \rightarrow \bar{B}$ oscillations will be

$$\frac{N_{signal}}{2} e^{-\frac{\Gamma t}{\hbar}} \left(\cosh \frac{\Delta \Gamma t}{2\hbar} - \cos \frac{\Delta m t}{\hbar} \right) + \frac{N_{back}(t)}{2} \sim e^{-\frac{\Gamma t}{\hbar}} \left(\cosh \frac{\Delta \Gamma t}{2\hbar} - D_{back} \cos \frac{\Delta m t}{\hbar} \right)$$

and the oscillation amplitude will be reduced by an amount

$$D_{back} = \frac{N_{signal} \cdot \cosh \frac{y t}{\tau}}{N_{signal} + N_{back}(t) e^{\frac{t}{\tau}}} .$$

Neglecting the proper time dependence of this dilution factor (that is supposing that the background is mainly due to B -hadron decays and therefore has approximately the same proper time exponential decay as the signal [15]), we have taken $D_{back} \approx 0.71$ which corresponds to the 2:1 signal/background ratio.

6 Prospects for x_s measurements

For $6 \cdot 10^4 \text{ pb}^{-1}$ integrated luminosity the number of reconstructed B_s^0 -s would reach ~ 8000 from the analyzed channel alone. Another ~ 16000 B_s^0 -s are expected from the $B_s^0 \rightarrow D_s^- \pi^+$ channel [9, 10].

For events in which B_s^0 meson does not oscillate before its decay, the D_s meson and the tagging muon have equal sign charges. If the B_s^0 meson oscillates, opposite charge combination emerges. The corresponding decay time distributions are

$$\begin{aligned}\frac{dn(++)}{dt} &= \frac{N}{2\tau} e^{-\frac{t}{\tau}} \left(1 + D \cos\left(\frac{x_s t}{\tau}\right) \right) \\ \frac{dn(+-)}{dt} &= \frac{N}{2\tau} e^{-\frac{t}{\tau}} \left(1 - D \cos\left(\frac{x_s t}{\tau}\right) \right)\end{aligned}\quad (10)$$

D is the product of all dilution factors and N is the total number of reconstructed B_s^0 -s.

The unification of samples from $B_s^0 \rightarrow D_s^- a_1^+$ and $B_s^0 \rightarrow D_s^- \pi^+$ decay channels allows to increase x_s measurement precision.

Fig.7 and Fig.8 show the corresponding

$$A(t) = \frac{\frac{dn(++)}{dt} - \frac{dn(+-)}{dt}}{\frac{dn(++)}{dt} + \frac{dn(+-)}{dt}} = D \cos\left(\frac{x_s t}{\tau}\right)$$

asymmetry plots for $x_s = 20$ and 35 .

7 Conclusions

It seems to us that $B_s^0 \rightarrow D_s^- a_1^+$ decay channel is almost as good for the B_s -mixing exploration as previously studied $B_s^0 \rightarrow D_s^- \pi^+$ and enables us to increase signal statistics about 1.5 times. Further gain in signal statistics can be reached [9, 10] by using $B_s^0 \rightarrow J/\psi K^*$ decay mode and considering other decay channels of D_s^- . These possibilities are under study.

We refrain from giving any particular value of x_s as an attainable upper limit. Too many uncertainties are left before a real experiment will start. Note, for example, that about two times bigger branching ratios for both $B_s \rightarrow D_s^- \pi^+$ and $B_s \rightarrow D_s^- a_1^+$ decay channels are predicted in [16]. $\sim 500 \mu\text{b}$ as a $b\bar{b}$ production cross section can also have significant variation in real life [17].

So although the results of this investigation strengthen confidence in reaching x_s as high as 40 [10], it should be realized that some theoretical predictions about B_s -physics and collider operation were involved and according to T.D.Lee's first law of physicist [18] "without experimentalist, theorist tend to drift". However maybe it is worthwhile to recall his second law also "without theorist, experimentalists tend to falter".

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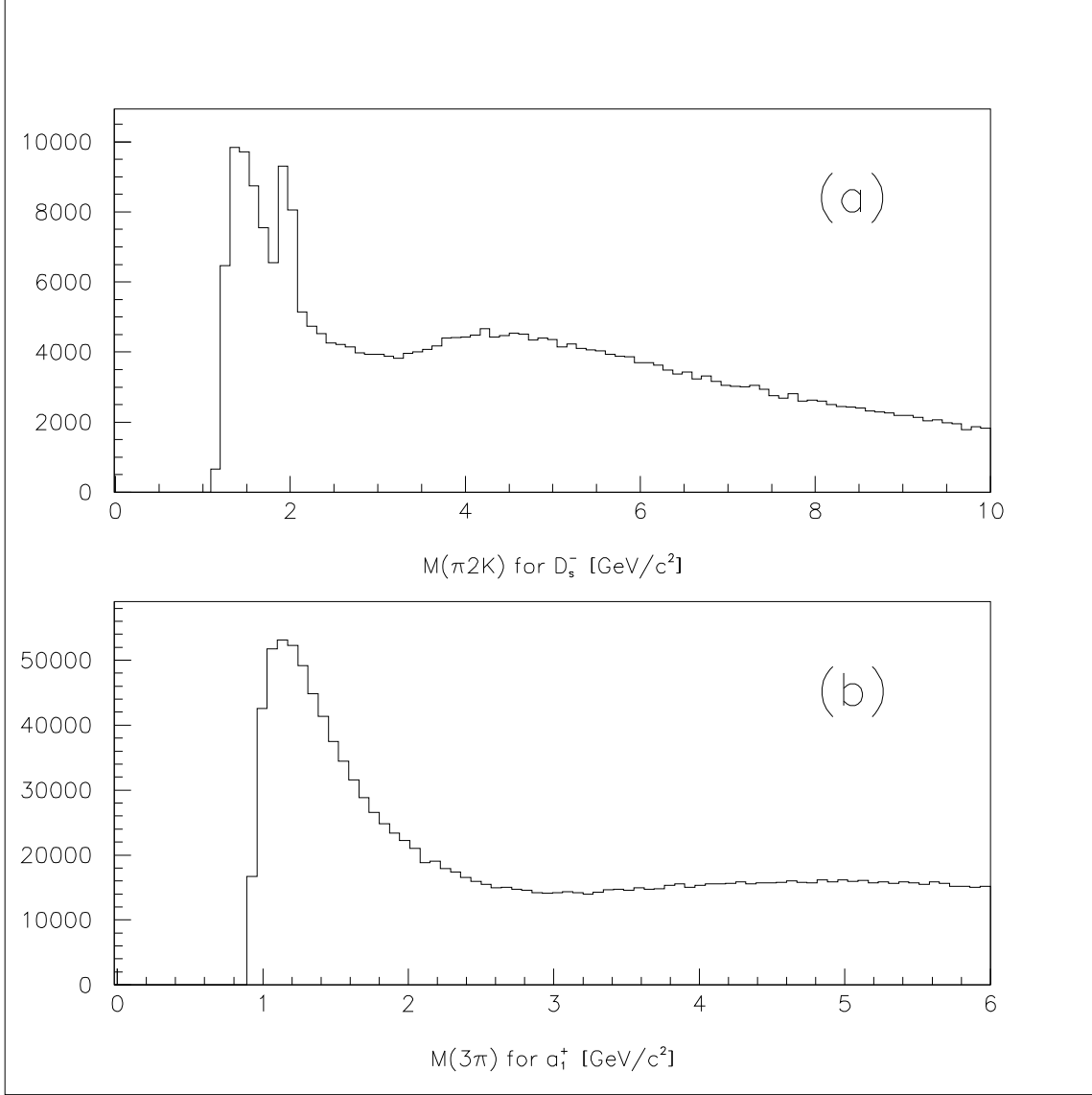


Figure 1: Invariant mass distributions of three charged particle combinations in signal events, assuming $2K + \pi$ (a) or 3π combination (b) as described in the text.

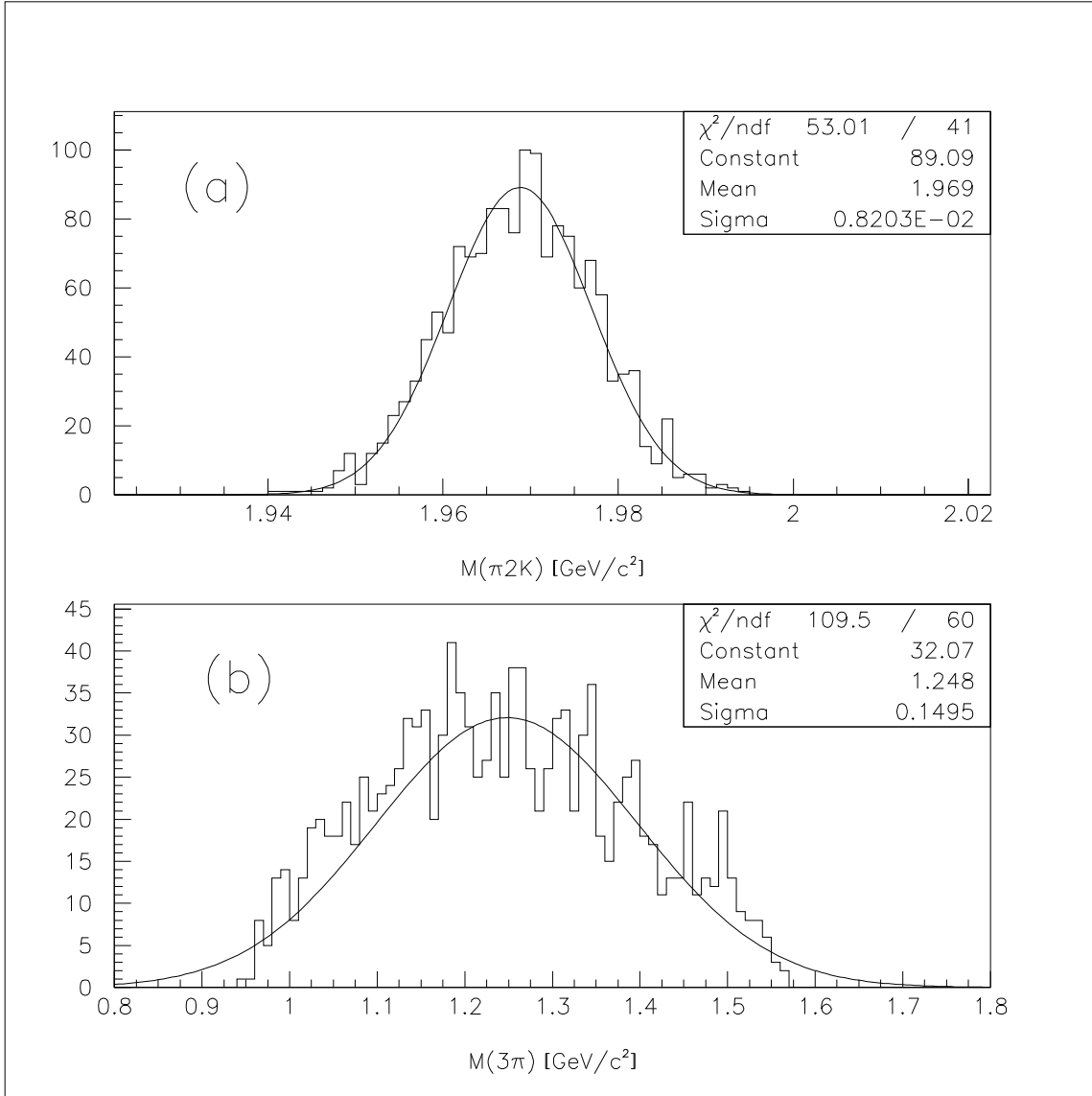


Figure 2: Three particle invariant mass distributions of reconstructed D_s^- and a_1^+ events.

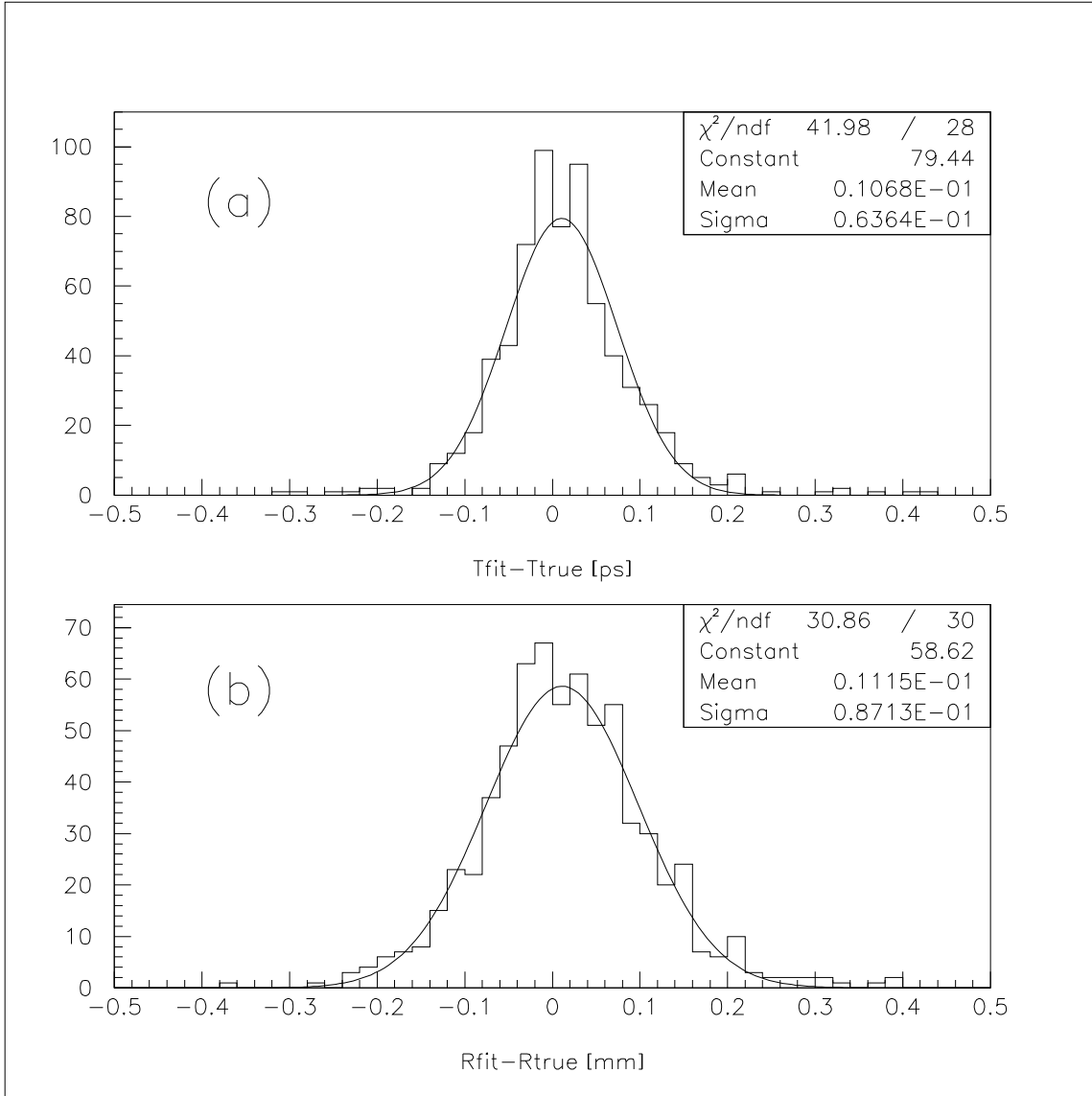


Figure 3: Proper time (a) and transverse radius (b) resolutions for the reconstructed B_s^0 decay vertex.

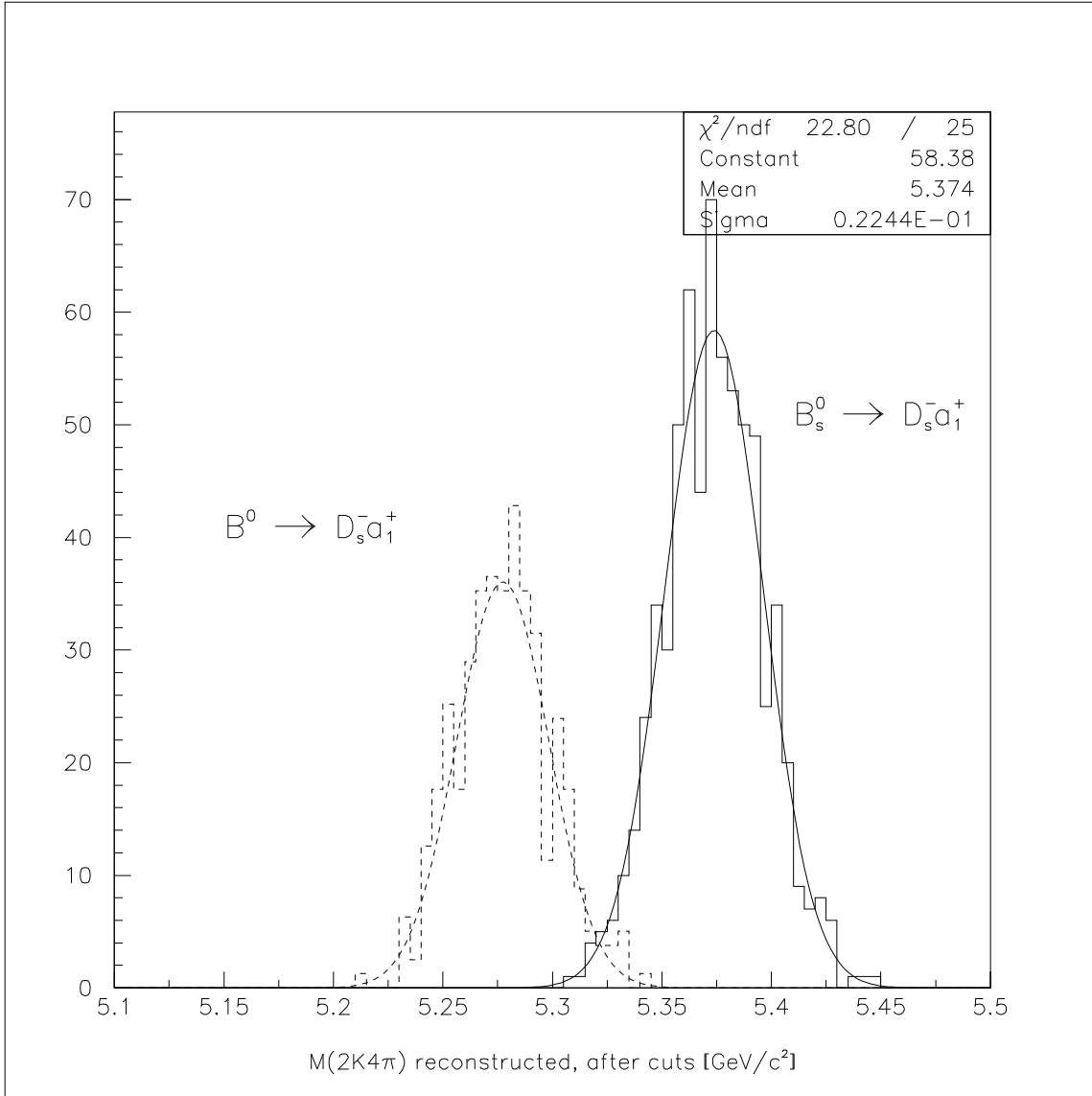


Figure 4: Six particle invariant mass distribution corresponding to the B_s^0 meson. Dashed line - expected upper limit for background from B^0 decay.

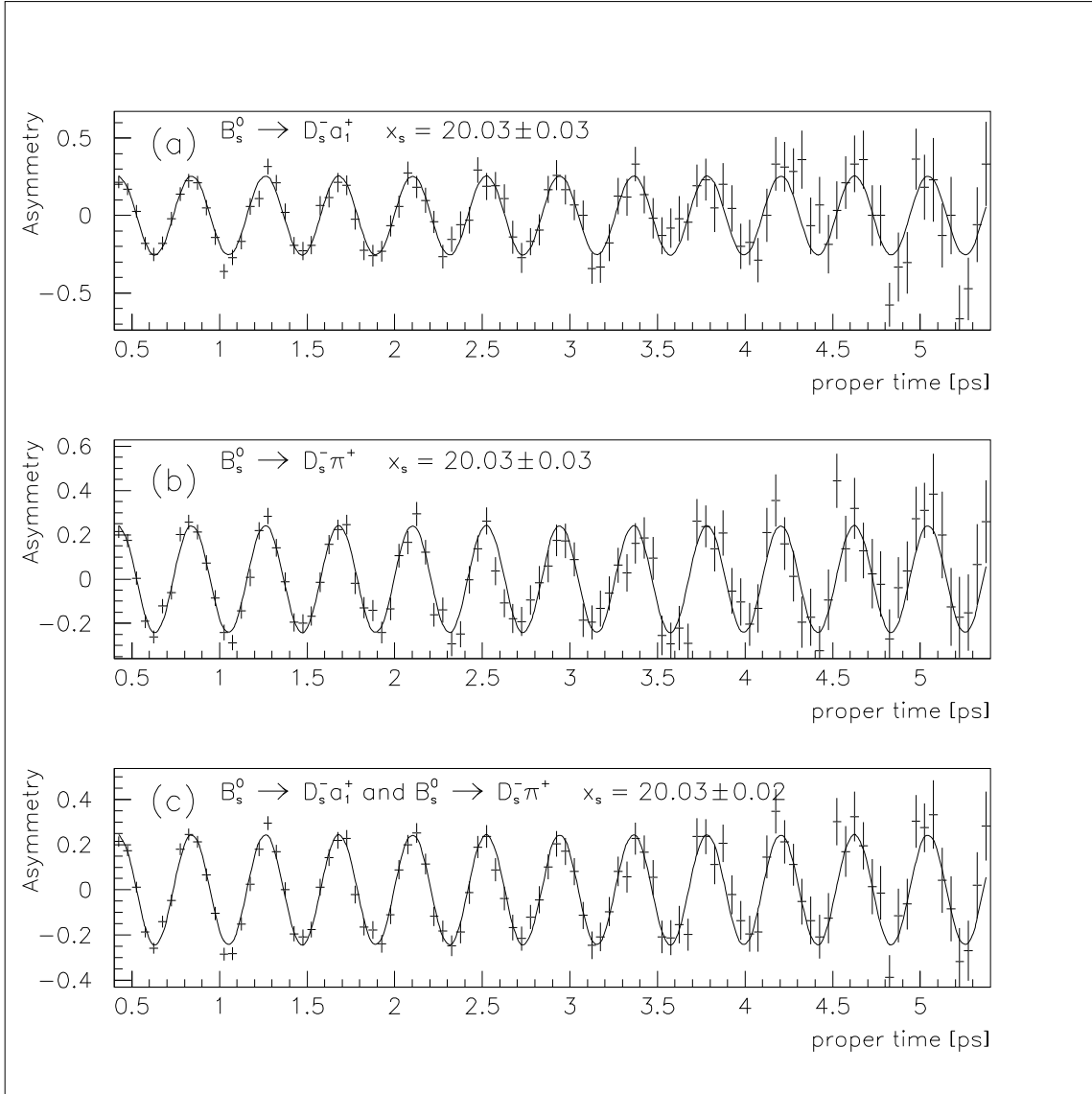


Figure 5: Asymmetry distributions for $B_s^0 \rightarrow D_s^- a_1^+$ (a), $B_s^0 \rightarrow D_s^- \pi^+$ (b) and when both channels are used (c), for $x_s = 20$.

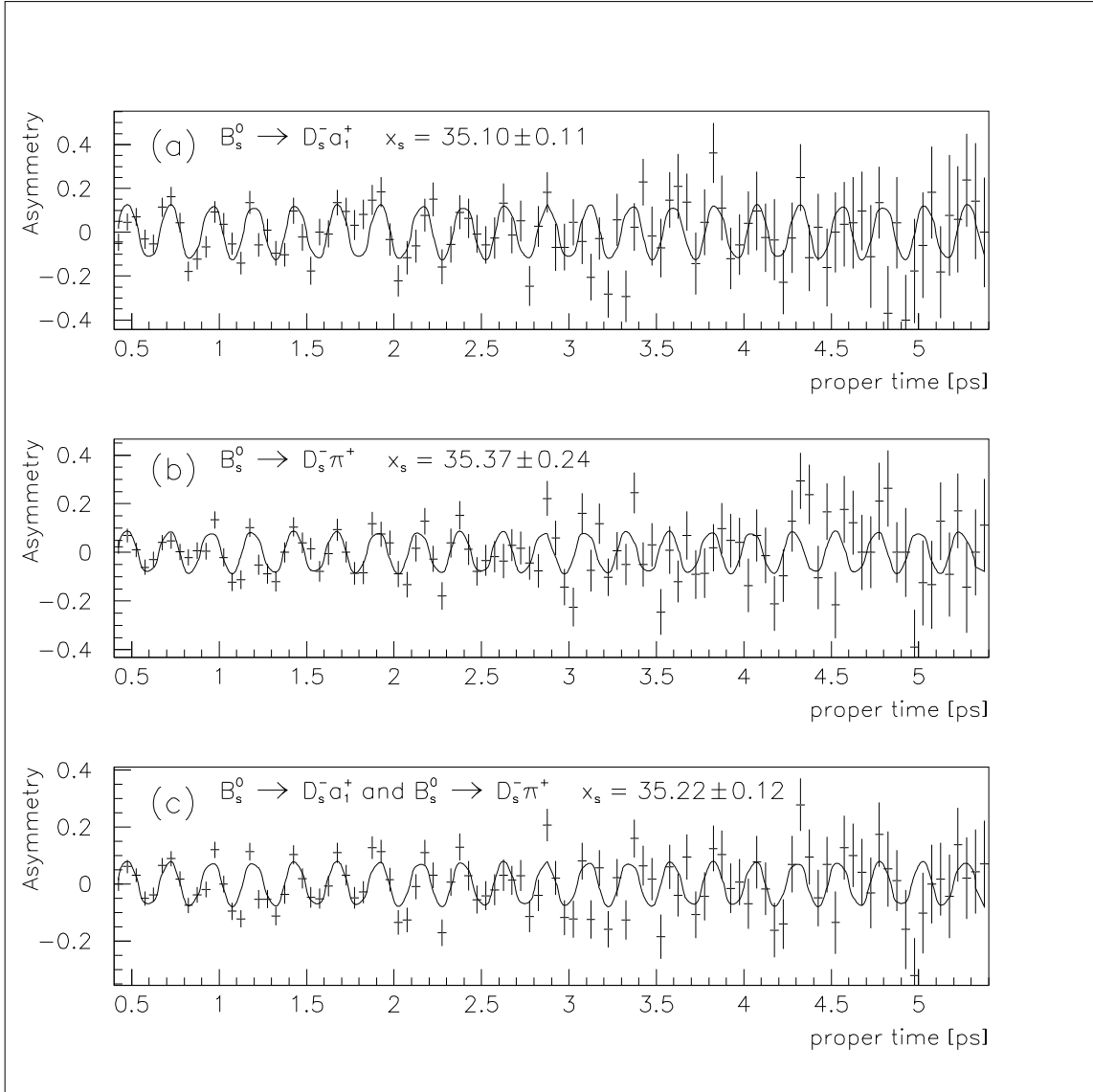


Figure 6: Asymmetry distributions for $B_s^0 \rightarrow D_s^- a_1^+$ (a), $B_s^0 \rightarrow D_s^- \pi^+$ (b) and when both channels are used (c), for $x_s = 35$.